

Open-ocean sea scallop (*Placopecten magellanicus*) culture trials in Chaleur Bay, Canada: Comparing culture gears and husbandry practices

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ABSTRACT

The growth and survival of sea scallops (*Placopecten magellanicus*) cultured in an exposed environment were assessed. The study site was an open-ocean mussel farm site in Chaleur Bay, Canada from which mussels (*Mytilus edulis*) have been harvested since 2004. The grower wanted to diversify his operation by cultivating scallops. Various aquaculture gears and husbandry approaches were tested: Pearl nets, Lantern nets, Dark Sea trays, OysterGro® and Kenny cabins. The Kenny cabin is a non-patented culture gear that was conceived and constructed by the owner and operator of Kenny Aquaculture Inc. The husbandry practices compared were: 1) grown two years in suspension, 2) grown two years on the bottom and 3) grown the first year in suspension and the second year on the bottom. Scallops cultured in suspension for two years had the highest growth rates except for those that were in heavily fouled gear. The gear with the best performance in terms of scallop growth rate (0.078 ± 0.015 mm/day) and survival rate ($99.2\% \pm 2.0\%$) was the Kenny cabin. Scallops grown in Lantern nets exhibited the highest growth rate (0.079 ± 0.019 mm/day) but had the lowest survival rate ($77.2\% \pm 17.6\%$). Since the Kenny cabin is rigid and sturdy while the Lantern net is flexible, the effect of wave action is suspected to be the principle contributor to the lower scallop survival in Lantern nets. The Kenny cabin and OysterGro® are not as easy to handle or to stack as Lantern nets. Therefore, in choosing gear other than the traditional Lantern net, a cost-effectiveness analysis should be done because the benefits of the higher survival rate could be offset by a higher labour cost. The sea scallop spat collection potential of the site was also assessed by deploying spat collector bags at the appropriate time. Based on the growth and survival rates of the cultured scallops and sea scallop spat collection rates (451.33 ± 97.45 /bag) observed in this study, farming sea scallop in Chaleur Bay could be successful, as it is in other parts of Atlantic Canada.

RÉSUMÉ

La croissance et la survie du pétoncle géant (*Placopecten magellanicus*) cultivé dans un environnement exposé ont été évaluées. Le site d'étude est une ferme mytilicole en pleine mer dans la Baie-des-Chaleurs Canada à partir de laquelle des moules (*Mytilus edulis*) ont été récoltées depuis 2004. L'aquiculteur s'intéresse à diversifier sa ferme en y ajoutant l'élevage du pétoncle. Divers engins de culture et de méthodes d'élevage ont été testés: les Paniers japonais, les Lanternes, les cassiers Dark Sea, OysterGro® et les cabanes Kenny. La cabane Kenny est un engin de culture non breveté qui a été conçu et construit par le propriétaire et l'opérateur de Kenny Aquaculture Inc. Les pratiques d'élevage qui ont été comparés étaient: 1) cultivé deux ans en suspension, 2) cultivé deux ans sur le fond et 3) cultivé la première année en suspension et la deuxième année sur le fond. Les pétoncles cultivés en suspension pendant deux ans ont des taux de croissance plus élevés, sauf pour ceux dans les engins avec beaucoup de salissures. L'engin de culture le plus performant en ce qui concerne le taux de croissance ($0,078 \pm 0,015$ mm/jour) et le taux de survie des pétoncles ($99,2\% \pm 2,0\%$) était la cabane Kenny. Les pétoncles élevés dans les Lanternes avaient le taux de croissance le plus élevé ($0,079 \pm 0,019$ mm/jour), mais le plus faible taux de survie ($77,2\% \pm 17,6\%$). La cabane Kenny est rigide et robuste, tandis que la Lanterne est flexible. Il est soupçonné que de l'effet de l'action des vagues est le contributeur principal à cette plus faible survie des pétoncles dans les Lanternes. La cabane Kenny et l'OysterGro® ne sont pas aussi faciles à manipuler ou à empiler que la Lanterne. Par conséquent, avant de choisir un engin d'élevage autre que la Lanterne traditionnel, une analyse coût-efficacité doit être entreprise, car le bénéfice d'une survie plus élevée ne pourra peut-être pas contrebalancer le coût plus élevé de la main-d'œuvre. Le potentiel du captage de naissains de pétoncle géant au site a également été évalué en déployant des sacs collecteurs au moment opportun. D'après les taux de survie et de croissance des pétoncles élevées et le taux de captage des naissains de pétoncle géant (451.33 ± 97.45 /sac) observés dans cette étude, le pétoncle géant pourrait être cultivé dans la Baie-des-Chaleurs avec succès, comme qu'il est dans d'autres régions du Canada atlantique.

1.0 INTRODUCTION

In the Gulf Region, sea scallops (*Placopecten magellanicus*) also called giant scallops, have been identified as a prospective specie for aquaculture. Penny and Mills (2000) demonstrated that growing sea scallops is economically viable in current market and financial conditions. Sea scallops are farmed in Québec, Nova Scotia, Newfoundland and in the French islands of Saint-Pierre & Miquelon (Davidson and Mullen 2005). In Québec, a unique market for farmed sea scallops has been developed (Pec-Nord 2013) which avoids direct competition with the wild fishery.

Kenny Aquaculture Ltd, an open-ocean mussel farm in Chaleur Bay, was interested in diversifying its operation to include sea scallop aquaculture. Scallop farmers can use several types of gears and techniques to grow-out juvenile scallops to market size including Pearl nets, Lantern nets, trays, large cages, ear hanging and sea ranching. Parsons and Robinson (2006) report that the pyramidal shaped Pearl nets, trays or Lantern nets are typically used for scallop aquaculture. Nowlan *et al.* (2011) found that Lantern nets showed the most promise in terms of ease of use, cost, and scallop survival when growing sea scallops in the Northumberland Strait.

In 2004 to 2008, Pecten UPM/MFU Inc, a non-profit organization, investigated the feasibility of growing sea scallops. Sudden upward and downward temperature fluctuations were recorded at their suspended culture site in Chaleur Bay and in the second year of culture, the scallop survival was less than 50% in some culture gear (Nowlan *et al.* 2011). Dickie (1958) observed a reduced mobility in sea scallops when they were subjected to sudden upward or downward temperature fluctuation and he suspected it to be an indirect cause of increased mortality in scallops. Davidson (1998) demonstrated that sea scallops start diverting energy to gonad production when their shell height is as small as 20 mm. However, complete emission of gametes were only observed in scallops 60 mm or greater. Nowlan *et al.* (2011) suggested that the combination of temperature fluctuation stress and gonad development stress may have contributed to the mortality observed in the second year. Before Kenny Aquaculture Ltd invest in gear to culture sea scallops, it was deemed important to investigate the performance of the sea scallops utilising various gear types and husbandry practices to determine which are best adapted to Chaleur Bay to minimizing the high mortality expected in the second year.

Kenny Aquaculture Ltd also wanted to determine if wild sea scallop spat could be collected economically at their site for their own use and /or to sell to other growers. Sites where spat mesh bag collectors contain over 500 scallop spat/bag with minimal amounts of other species or debris or silt are considered to be economically viable for scallop spat collection (Cropp and Frankish 1988).

The primary objective of this study was to assess the performance of sea scallops cultivated in an exposed open-ocean environment using various gear types and husbandry approaches to minimize the mortality rate. Specifically the project compared the growth and survival of sea scallops grown in suspension and on the bottom at an open ocean site in Chaleur Bay: 1) sea scallops grown in suspension for two years 2) sea scallops grown on the bottom for two years and 3) sea scallops grown in suspension the first year and transferred to the bottom for the second year. In short, the study aims is to determine if the shell growth and survival rates of sea scallops grown two years in suspension or on the bottom are significantly different that those grown the first year in suspension and second year on the bottom.

A secondary objective was to determine if the Kenny Aquaculture Ltd culture site could serve as an economically viable sea scallop spat collection site which would require that sea scallop spat collection rate at the site be equal to or greater than 500/sea scallop spat per bag. (H_0 spat count <500, H_A spat count \geq 500).

2.0 METHODOLOGY

2.1 FARM SITE

The Kenny Aquaculture Ltd farm is located in Chaleur Bay off the coast of Stonehaven, New Brunswick (NB), Canada on NB provincial lease site ms1013 which has an area of 0.43 Km² (43 hectares) (Figure 1). The central latitude/longitude of the site is 47.7586 / 65.3860.

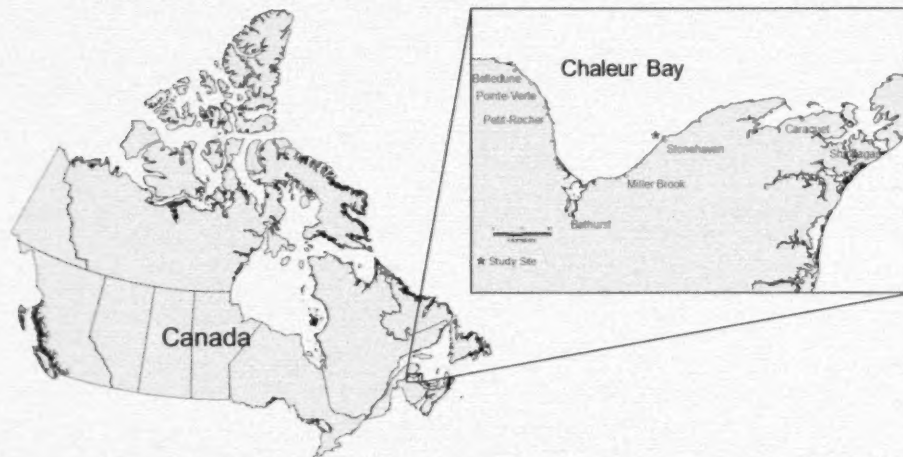


Figure 1. Location of the Kenny Aquaculture Ltd farm site.

This aquaculture site, which is the only open-ocean mussel farm in the Gulf Region, has an average depth of 23 m (75ft). It is exposed to predominantly northern winds and is ice covered in the winter. Mussels have been harvested annually from this site since 2004. In 2008, the Kenny Aquaculture site permit was modified to include sea scallops. Prior to this study, the operator deployed a few scallop spat collector bags in 2008 and 2009. An average of only 20 sea scallop spat/bag was collected.

2.2 TEMPERATURE DATA

Two VEMCO Minilog temperature recorders were deployed for the duration of the study. One of the recorders was placed with the suspended gear and the other with the bottom gear. The VEMCO Minilog in the suspended gear was also equipped with a depth sensor (Figure 2).

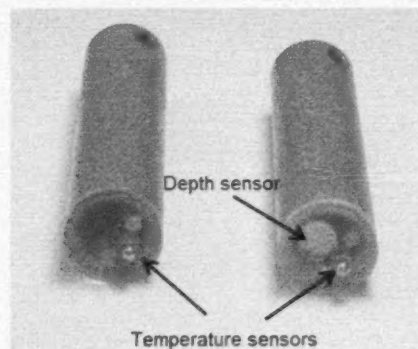


Figure 2. VEMCO minilog temperature recorders.

2.3 GEAR TYPES AND LONGLINES

The gear types used in this study were: Pearl nets, Lantern nets, Dark Sea trays, OysterGro[®] culture systems and Kenny cabins (Figure 3). Pearls nets (33 cm X 33 cm) and Lantern nets (46 cm diameter) are traditional scallop culture gear, which are used worldwide. Dark Sea trays (60 cm X 60 cm) and OysterGro[®] culture systems were conceived to grow oysters. Kenny cabins have been created and fabricated by the owner and operator of Kenny Aquaculture Ltd to grow scallops in Chaleur Bay. Like the OysterGro[®], the Kenny cabins have an outside frame made with Aquamesh[®]. The rectangle frame of the Kenny cabin is made just large enough to accommodate 3 vertically stacked Vexar[®] bags (87cm X 46 cm) that are commonly called oyster bags. Scallop spat collection bags were made with 3 mm mesh bags filled with two pieces of Netron, a polyethylene mesh measuring 40 cm × 100 cm (Figure 4). This type of collector bags has proven to be effective (Niles *et al.* 2005).

All gear types were deployed on the same longlines and the scallop spat collectors were deployed on separate longlines.

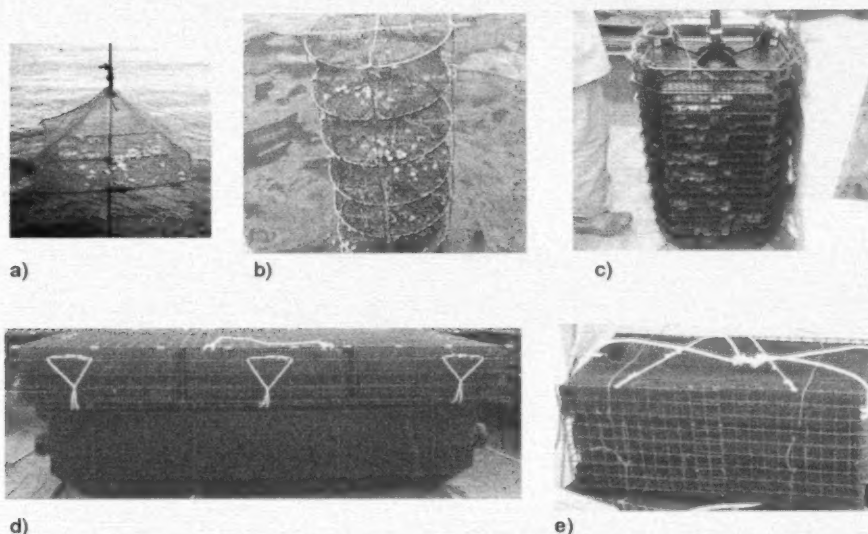


Figure 3. a) Pearl net, b) Lantern net, c) Dark Sea trays, d) OysterGro[®] culture system with bottom floats e) Kenny cabin.

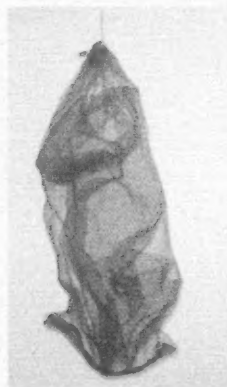


Figure 4. Scallop spat collector bag.

2.4 STOCKING DENSITIES

The growth rate of farmed juvenile sea scallops has been found to be inversely proportional to the stocking density (Côté *et al.* 1993; Penney 1995). In evaluating the growth and survival of sea scallops farmed in various grow-out gear in Passamaquoddy Bay NB, Parsons and Dadswell (1994) successfully avoided the effect of density by following Imai's (1977) stocking guideline. According to Imai (1977), at the end of the grow-out cycle, the scallops should not cover more than 30% of the floor area of the gear. The surface area of each gear was simply calculated from their dimension. For the Dark Sea Tray, the areas occupied by the ridges, the stand pipe and the cut-off corners were subtracted from the area calculated based on its dimension. In this study, the shell heights that were expected at the end of the first year and second year grow-out cycle were 40 mm and 60 mm respectively. Based on Imai's (1977) recommendation and assuming 100% survival, the densities calculated for each gear-type are reported in Table 1. Since the sea scallops are approximately circular in shape, the formula for the area of a circle ($\pi \cdot r^2$) was used to calculate the area of each scallop.

Table 1. Surface area available at each level for each culture gear and selected density for the targeted shell height.

Gear	Dimensions	Surface area cm ²	Mesh Size mm	30% of surface area cm ²	Density to reach 40 mm	Density to reach 60 mm
Pearl net (each)	33 cm x 33 cm	1089	4	326.7	26	---
Lantern Net (each level)	46 cm diameter	1661	14	498	---	17
Dark Sea tray (each tray)	60 cm x 60 cm	2885.5*	9 to 10	865.65	68	30
Vexar [®] bag** (each)	87 cm x 46 cm	4002	9	1200	95	42

*areas occupied by the ridges, the stand pipe and the cut-off corners were subtracted

**Vexar[®] bags are in the OysterGro[®] and the Kenny cabin.

2.5 EXPERIMENTAL SET-UP AND PROCEDURES

The various gear types and the other required equipment were purchased in the summer 2010 and the longlines were then placed on the farm site. In the fall of 2010, one year old sea scallop spat with an average shell height of 9.7 ± 2.0 mm were purchased from Sea Perfect Cultivated Product Ltd following the approval of the introduction and transfer committee. The gear had been purchased with the plan of buying spat with a 15 to 20 mm shell height but only the smaller spat were available. Therefore, the mesh size of the Lantern nets, Dark Sea trays and Vexar[®] bags was too large to accommodate the smaller spat without temporary modifications. To prevent the scallop spat from escaping the following modifications were done: 1) 4.5 mm mesh Pearl bags were used instead of Lantern nets 2) 6 mm Vexar[®] mesh liners were placed inside Dark Sea trays and 3) 1 mm mesh onion bags with pieces of pipe were placed inside Vexar[®] bags (pipe pieces prevented the onion bags from collapsing). In 2010, the prescribed densities in Table 1 were followed but the numbers of scallops were estimated by volume due to the small shell size. Also, an extra 10% was added to compensate for the expected loss: 1) it is difficult to differentiate between live and dead scallops when they are small 2) escaping small scallops 3) mortality cause by the gear modification.

The gear types, replicates and location of the gear for the first growing season are listed in Table 2 and illustrated in Figure 5. Winter ice cover has been reported in Chaleur Bay (www.ec.gc.ca/glaces-ice/default.asp), so to avoid the winter ice and also to minimize wave action; the suspended culture gears were placed at a depth of at least 6 m (20ft) below the surface. Le Quéré (1992) observed the temperature and salinity distribution at the entry of

Chaleur Bay to show the strongest stratification in June and the degree of stratification decreased in mid-September to mid-October.

Table 2. The gear types, the replicates and the location of gears for the first growing season, fall 2010 to fall 2011.

Depth			
Suspension		Bottom	
Culture gears	Replicates	Culture gears	Replicates
Pearl net (string of 10)	6	OysterGro® culture system	3
Dark Sea tray (10 trays)	6		
OysterGro® culture system	6		
Kenny cabin	3		

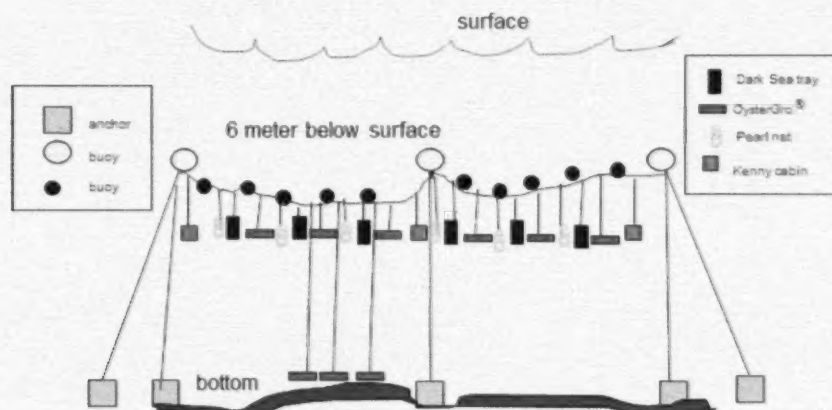


Figure 5. Schematic of the experimental set-up from fall 2010 until fall 2011.

Also, in the fall 2010, the spat collectors (~700 bags) were deployed on a longline that was suspended at least 6 m (20ft) from the bottom (Figure 6).

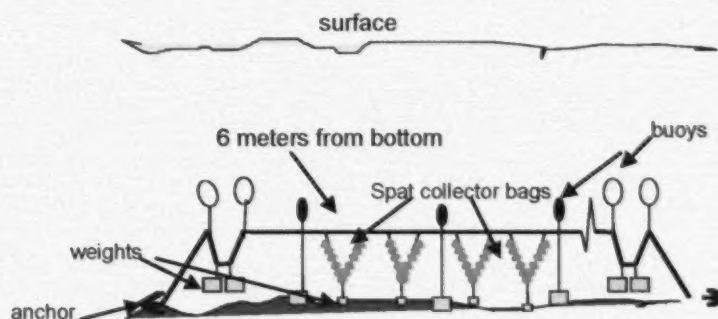


Figure 6. Schematic of sea scallop spat collectors deployed from fall 2010 until fall 2011.

In the spring and summer 2011, the suspended and bottom culture gears were visited to make sure they were still securely in place and at the desired locations. In the fall 2011, each gear type was retrieved to count and measure the shell height of the scallops. Photographs of the fouling on each of gear type were taken. The scallops were then placed in clean culture gear at the

densities indicated in Table 1 for each gear type with the replicates and location as listed in Table 3 and illustrated in Figure 7.

Table 3. The gear types, the replicates and the location of gears for the second growing season (fall 2011 to August 13, 2012) and the gear type used the previous season.

Suspension		Bottom	
Gear type (<i>Previous season</i>)	Replicates	Gear type (<i>Previous season</i>)	Replicates
Lantern nets (<i>Pearl nets</i>)	3	OysterGro [®] (<i>bottom OysterGro[®]</i>)	3
Dark (<i>Dark Sea tray</i>)	3	OysterGro [®] (<i>Pearl net</i>)	3
OysterGro [®] (<i>suspended OysterGro[®]</i>)	3	OysterGro [®] (<i>Dark Sea tray</i>)	3
Kenny cabin (<i>Kenny cabin</i>)	3	OysterGro [®] (<i>suspended OysterGro[®]</i>)	3

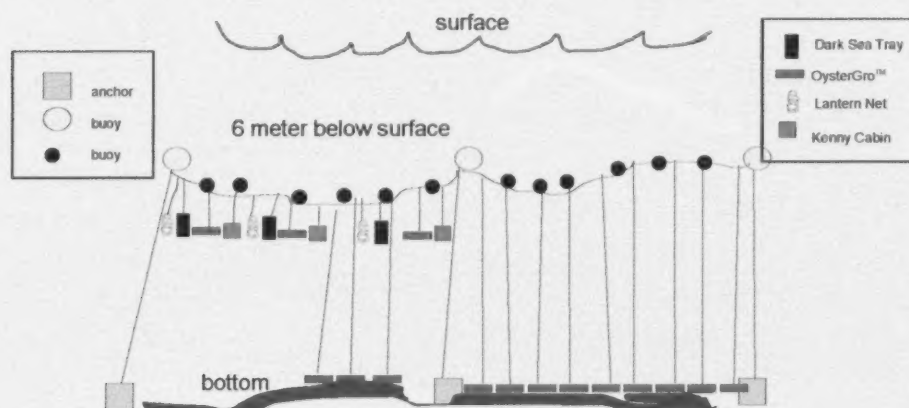


Figure 7. Schematic of the experimental set-up from fall 2011 until August 13, 2012.

The temperature recorders were retrieved and the data were downloaded. The recorders were then re-programmed and re-deployed. The scallop spat collectors were retrieved and cleaned. Three spat collector bags from each end and three from the middle were taken. These spat collector bags (9) were kept frozen until they were processed in the laboratory to determine their contents.

In the spring and summer 2012, the suspended and bottom gear were visited to make sure they were still properly in place. On August 13, 2012, all the gear was retrieved. The fouling on the gear was photographed. The scallops and other species which took up residence in the gear were removed and frozen until they could be measured. The shell height of all the scallops was measured in the laboratory to the nearest mm. The other species were identified and counted. Unfortunately, the freezing degraded some species which made identification difficult.

2.6 MEASUREMENTS

2010

The scallop spat that were purchased from Sea Perfect Cultivated Ltd were transported over ice packs in a styrofoam cooler from Arichat NS to Stonehaven NB on November 1, 2010. The spat were stored overnight in a cool protected area. The shell heights (Figure 8) of a random sample of 177 scallop spat were measured on November 2, 2010 as a representative initial shell height for all the gear types.

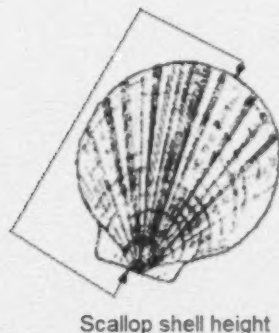


Figure 8. Sea scallop shell height

2011

Between October 12 and 18, 2011, each gear type was retrieved and the scallops were removed. The shell heights of the sampled scallops were measured. The samples consisted of all the scallops from the following locations of each gear type: Pearl nets, top, middle and last, Dark Sea trays, top, middle and last tray, OysterGro[®], 3 of the 6 Vexar[®] bags, Kenny cabins, the 3 Vexar[®] bags. It was not possible to accurately determine the survival from 2010 to 2011 because the exact numbers initially placed in the gear were not known. The gear was exchanged for clean gear. The scallops were returned to the appropriate gear as described in EXPERIMENTAL SET-UP AND PROCEDURES (page 11) and at appropriate densities (Table 1).

2012

On August 13, 2012, the study was terminated so all the gear was retrieved except for one OysterGro[®] (Lantern net to OysterGro[®] bottom) that broke off the longline. The shell height of each scallop was measured to the nearest mm. The top shells of each empty shell were counted as a dead scallop. To determine the survival rate and the growth rate the following formulas were employed.

$$\text{Survival rate} = (\# \text{ of live scallops} / (\# \text{ of live scallops} + \# \text{ of top shell})) * 100$$

$$\text{Growth rate} = (\text{shell of scallop at date taken out of water} - \text{shell height of scallop at date put in the water}) / \# \text{ of days in the water.}$$

When an organism's growth rate is predominantly under temperature control its rate of development can be characterized using a system called growing-degree day (GDD). (<http://agron-www.agron.iastate.edu/Courses/agron212/Calculations/GDD.htm>). This GDD concept assumes that:

1. There is a base temperature below which the organism does not grow or grows very slowly.
2. The growth rate increases with temperature above the base temperature.
3. Growth and development are closely related to daily temperature mean accumulations above the base temperature.

In this study, the GDDs were determined separately for scallops in suspension and scallops on the bottom. GDD was calculated by subtracting 4°C, the base temperature needed for growth for sea scallops (Young-Lai and Aiken 1986), from each daily mean temperature recorded by the loggers over the study period. Negative results were set to zero. The sum of all results for a given scallop category was interpreted as the GDD.

2.7 ANALYSIS

After the first year, the scallop shell height and growth rate data were analysed using ANOVAs to determine if there was a significant difference in scallops grown in the various gear types located in suspension or on bottom as listed in Table 2. After the second year, ANOVAs were used to determine if there were differences in the shell height, growth rate, and survival rate of scallops grown in the various gear types located in suspension or on bottom as listed in Table 3. When significant differences were found, the Scheffé multiple comparison procedures were employed to reveal where the differences occurred.

To determine if the scallop spat count obtained from the collector bags deployed on Kenny Aquaculture Ltd farm site meets or exceeds the commercially viable count (500 spat/ bag) a t-test (H_0 spat count <500, H_A spat count \geq 500) was conducted.

All analyses were conducted using Statistical Analysis Software (SAS) version 9.1. For all tests, the significance level was 0.05. Tests of normality and homogeneity of variance were carried out for all data before analysis. The shell height and growth rate data were normally distributed with homogeneous variance. Normal distribution and homogeneity of the variance of the survival data could not be achieved even after attempting several transformations. The PROC NPAR1WAY could have been used to analyse nonparametric data, but this procedure does not include multiple comparisons analysis to determine where the differences occur. When using SAS, Hobbs (2009) indicated it was valid to use PROC GLM (which is designed to analyse data with a normal distribution) on nonparametric data, as it is robust to lack of normality. The advantage of using the PROC GLM is that there is multiple comparisons analysis available to determine where the differences occur.

3.0 RESULTS

3.1 TEMPERATURE

The average daily water temperature at the suspended gear level (6 m depth) and on the bottom (23 m depth) followed the same trend (Figure 9). Acute temperature changes are observed on the bottom and in suspension. The temperature never rose about 16°C even in the summer months. Since the water temperature in suspension was slightly warmer, the calculated growth degree day (GDD) for the sea scallops in suspension was 1005.3 and it was only 753.5 for the scallops on the bottom.

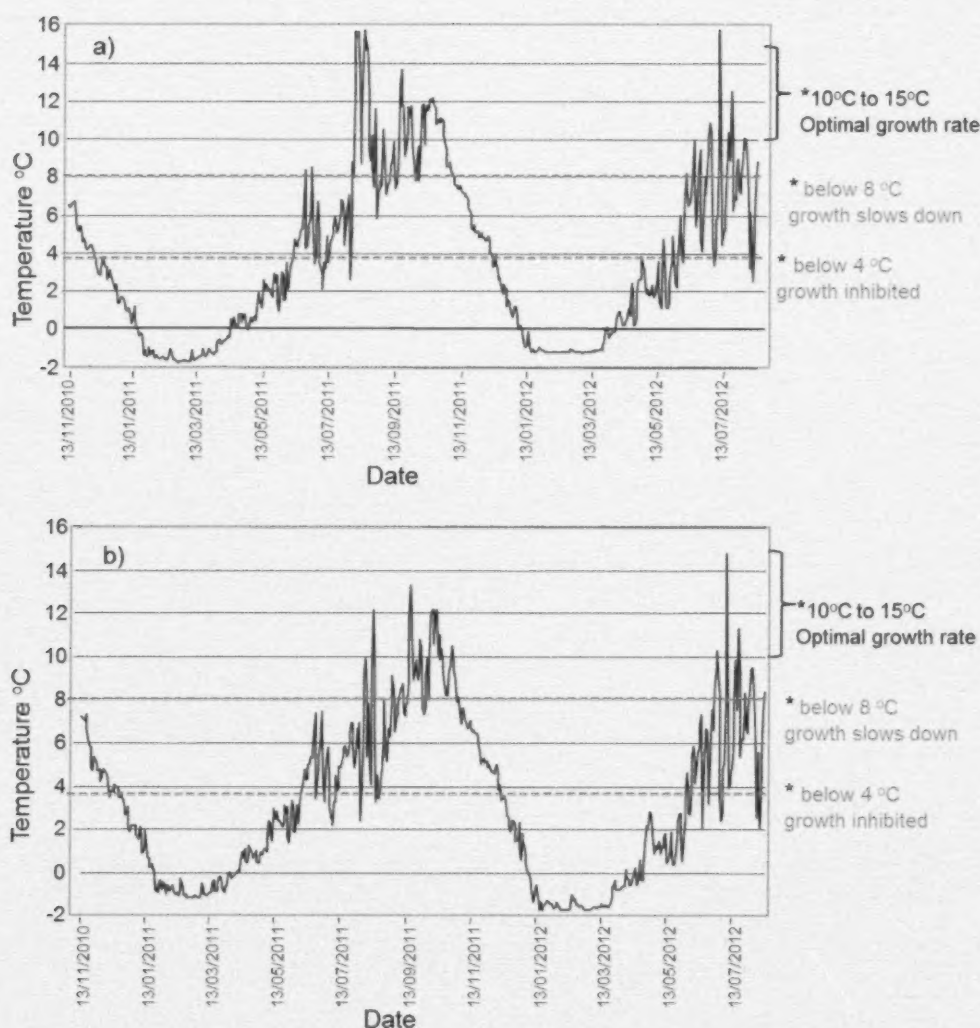


Figure 9. Average daily water temperature at study site 2010-2012: a) in suspension (6 m depth) b) on the bottom (23 m depth), *Young-Lai and Aiken (1986).

3.2 FOULING

The various gear types were retrieved nearly one year after they were deployed. There was fouling on all the gear types (Figure 10). The fouling organisms were mainly: *Hiatella* (*Hiatella arctica*), blue mussels (*Mytilus edulis*), hydroids (Unidentified sp. Family Campanulariidae), and barnacles (*Balanus* sp.) Also, inside some of the gear types, certain species took up residence with the farmed scallops. The species found inside the gear included: *Hiatella* (*Hiatella arctica*), hydroids (Unidentified sp. Family Campanulariidae), jingle shell (*Anomia simplex*), barnacle (*Balanus* sp.), shrimp (Unidentified sp.), blue mussels (*Mytilus edulis*), common seastars (*Asterias* sp.), blood stars (*Henricia* sp.), brittle stars (*Ophioderma* sp.), mud crab (Unidentified sp.), chiton (*Ischnochiton* sp.), sea cucumber (*Cucumaria frondosa*), Arctic shanny (*Stichaeus punctatus*), Iceland scallop (*Chlamys islandica*) and newly settled sea scallop (*Placopecten magellanicus*).

After the first year, the Pearl nets seem to have the largest amount of fouling (Figure 10a). After the second year, a large amount of fouling was on the suspended OysterGro[®]. This fouling consisted of a heavy set of *Hiatella* that completely covered the outside of the OysterGro[®] and a large amount of *Hiatella* was also found inside the Vexar[®] bags. *Hiatella* was also observed in relatively large numbers inside the Dark Sea trays even though they were not plentiful on the outside.

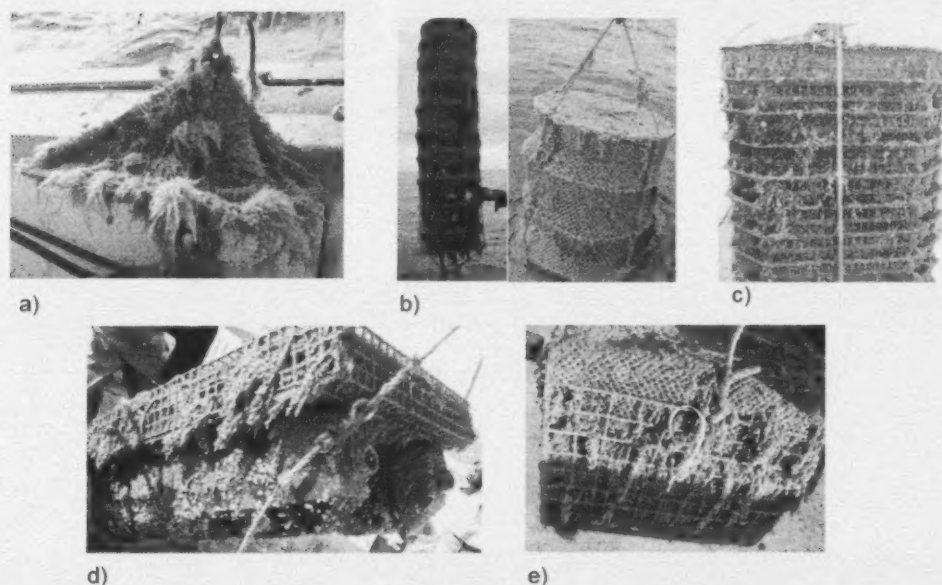


Figure 10. Photos of the fouling on the various gear types: a) Pearl net, b) Lantern net, c) Dark Sea trays, d) OysterGro[®] culture system with floats placed on at the bottom e) Kenny cabin.

3.3 GROWTH AND SURVIVAL

After one year, the scallops with the smallest shell heights and growth rates were those grown on the bottom in the OysterGro[®] and the highest was in those in suspended OysterGro[™] (Table 4 and Figure 11).

Table 4. Average (\pm standard deviation) shell heights and growth rates of scallops measured in 2010 and 2011.

Gear type	Gear code	Location of gear	Shell height \pm SD (mm)		Growth rate \pm SD mm/day
			Nov 2, 2010	Oct 12-18, 2011	
Pearl nets	PN	Suspended	9.7 \pm 2.0	31.8 \pm 4.0	0.064 \pm 0.012
Dark Sea trays	DST	Suspended	9.7 \pm 2.0	34.6 \pm 4.7	0.072 \pm 0.013
Kenny cabins	KC	Suspended	9.7 \pm 2.0	32.8 \pm 3.9	0.067 \pm 0.011
OysterGro [™] suspended	OGS	Suspended	9.7 \pm 2.0	35.6 \pm 5.1	0.075 \pm 0.015
OysterGro [™] bottom	OGB	Bottom	9.7 \pm 2.0	28.0 \pm 4.6	0.053 \pm 0.013

The ranking of the gear in terms of lowest to highest shell height is the same as the one for the growth rate. There were significant differences in scallop shell heights and growth rates after one year in the various gear types (for shell heights, ANOVA, $F=205.14$, $P<.0001$, for growth rates,

ANOVA, $F=203.44$, $P<.0001$). The shell height and growth rates of farmed scallops differed significantly between gear types except for those grown in the Pearl nets and the Kenny cabins (Scheffé multiple comparison, $F=2.37521$, $P=0.05$) (Figure 11).

a)			b)		
Gear code	Avg Shell height	NSD*	Gear code	Avg Growth rate	NSD*
OGB	28.0 ± 4.6		OGB	0.053 ± 0.013	
PN	31.8 ± 4.0		PN	0.064 ± 0.012	
KC	32.8 ± 3.9		KC	0.067 ± 0.011	
DST	34.6 ± 4.7		DST	0.072 ± 0.013	
OGS	35.6 ± 5.1		OGS	0.075 ± 0.015	

* Line indicates no significant difference based on the Scheffé multiple comparison procedure.

Figure 11. The lowest to the highest: a) average (\pm SD) shell height b) average (\pm SD) growth rate of scallops cultivated from 2010 to 2011.

The average (\pm standard deviation) shell height and growth rate of scallops from each gear type along with the percentage of survival from 2011 to 2012 can be found in Table 5.

Table 5. Average (\pm SD) shell heights, growth rates and survival rates of scallops measured in 2011 and 2012.

Gear type	Gear code	Location of gear	Shell height \pm SD (mm)		Growth rate \pm SD mm/day	--%-- Survival \pm SD 2011 to 2012
			Oct 12-18, 2011	Aug 13, 2012		
Lantern nets	LN	Suspended	31.8 ± 4.0	56.2 ± 4.9	0.079 ± 0.019	77.2 ± 17.6
Dark Sea trays	DST	Suspended	34.6 ± 4.7	52.6 ± 4.8	0.059 ± 0.016	84.2 ± 16.1
Kenny cabins	KC	Suspended	32.8 ± 3.9	56.8 ± 4.4	0.078 ± 0.015	99.2 ± 2.0
OysterGro [®] suspended	OGS	Suspended	35.6 ± 5.1	52.8 ± 5.4	0.056 ± 0.018	99.8 ± 0.6
OysterGro [®] bottom	OGB	Bottom	28.0 ± 4.6	50.4 ± 4.1	0.073 ± 0.014	92.9 ± 7.6
Lantern to OysterGro [®] bottom	LNOGB	Bottom	31.8 ± 4.0	51.2 ± 4.0	0.063 ± 0.013	95.2 ± 8.3
Dark Sea tray to OysterGro [®] bottom	DSTOGB	Bottom	34.6 ± 4.7	51.8 ± 4.3	0.056 ± 0.014	97.1 ± 5.9
OysterGro [®] suspended to OysterGro [®] bottom	OGSOGB	Bottom	35.6 ± 5.1	45.5 ± 4.2	0.032 ± 0.014	94.3 ± 9.6

As was the case after the first year, the lowest shell heights were from scallops grown on the bottom. The highest shell heights were found in scallops grown in suspension in the Lantern nets and the Kenny cabins. The ranking of the gear in terms of lowest to highest shell height is not the same as the one for the growth rate. There are significant differences among the scallop shell heights and growth rates after the second year from the various configurations of gear types and

husbandry approach (for shell heights, ANOVA, $F=293.4$, $P<.0001$, for growth rates, ANOVA, $F=551.93$, $P<.0001$). (Figure 12).

Gear code	Avg Shell height	NSD*	Gear code	Avg Growth rate	NSD*
OGSOGB	45.5±4.2		OGSOGB	0.032 ± 0.013	
OGB	50.4±4.1		DSTOGB	0.056 ± 0.014	
LNOGB	51.2±4.0		OGS	0.056 ± 0.018	
DSTOGB	51.8±4.3		DST	0.059 ± 0.016	
DST	52.6±4.8		LNOGB	0.063 ± 0.013	
OGS	52.8±5.4		OGB	0.073 ± 0.014	
LN	56.2±4.9		KC	0.078 ± 0.015	
KC	56.8±4.4		LN	0.079 ± 0.019	

* Line indicates no significant difference based on the Scheffé multiple comparison procedure.

Figure 12. The lowest to the highest: a) average shell height (\pm standard deviation) b) average growth rate (\pm standard deviation) of scallops cultivated from 2011 to 2012.

After two years, the lowest survival rates were recorded from scallops grown in Lantern nets and the Dark Sea trays while the highest survival rates were recorded from those in the suspended OysterGro® and the Kenny cabins (Table 3). The survival rate of scallops grown in Lantern nets differed significantly from all other gear except those grown in Dark Sea trays (Figure 13).

Gear code	Survival %	NSD*
LN	77.2 ± 17.6	
DST	84.2 ± 16.1	
OGB	92.9 ± 7.6	
OGSOGB	94.3 ± 9.6	
LNOGB	95.2 ± 8.3	
DSTOGB	97.1 ± 5.9	
KC	99.2 ± 2.0	
OGS	99.8 ± 0.6	

* Line indicates no significant difference based on the Scheffé multiple comparison procedure.

Figure 13. The lowest to the highest % survival rate (\pm standard deviation) of scallops cultivated from 2011 to 2012.

3. 4 SPAT COLLECTORS

The sea scallop collector bags were deployed on September 27, 2010 and retrieved September 20, 2011. Mean and standard deviation of sea scallop shell length was 11.21 ± 3.43 mm. The mean number of sea scallop spat in each collector was 451.33 ± 97.45 per bag. According to the results of the t-test, the mean count was not significantly different from a 500 count per bag (one-sample $t(8) = -1.4$, $1 P = 0.1953$). Many species were found in the collector bags (Figure 14). The most abundant species was the Iceland scallop (*Chlamys islandica*) followed by the Hiatella (*Hiatella arctica*) spat. Sea scallop spat were the third most abundant species.

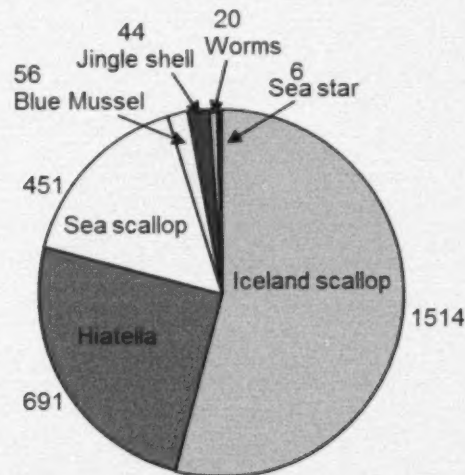


Figure 14. The average numbers of the most abundant taxa found in the sea scallop spat collector bags.

4.0 DISCUSSION

During the second year of culture, the aquaculture gear type with the best performance in terms of scallop growth rate (0.078 ± 0.015 mm/day) and survival rate ($99.2 \pm 2.0\%$) was the Kenny cabin. Despite the elevated growth rate (0.079 ± 0.019), the scallops grown in the traditional Lantern net had a lower survival rate that was significantly lower than all the other gear types except those grown in Dark Sea trays. Nevertheless, it was still $77.2 \pm 17.6\%$. According to Hardy (2006), a scallop farmer can have a viable commercial operation even when the scallop survival rate is as low as 50%. However, logic dictates that higher survival rates contribute to greater profitability.

In this study, handling was minimized because the sea scallop survival rate is known to be poor if they are handled too much (Dadswell 2005; Brulotte *et al.* 2008). Based on the results obtained by Nowlan *et al.* (2011) who also minimized handling, lower survival rates were expected among scallops grown in suspension during the second year. These authors suggested that the stress of sudden temperature fluctuations combined with the stress of diverting energy to reproduction may have contributed to the lower survival. When developing this study, it had been assumed that the sudden temperature changes Nowlan *et al.* (2011) observed at their suspended culture site were not as severe at the bottom since there are wild scallops found on the bottom in Chaleur Bay. However, in this study, sudden temperature fluctuations were recorded at the suspended depth and at the bottom. Yet, the husbandry practice of growing scallops the first year in

suspension in traditional Lantern nets and the second year on the bottom in OysterGro[®], did significantly improve the survival rate in scallops ($95.2\% \pm 8.3$ vs $77.2\% \pm 17.6\%$). Scallops in the bottom gear may not have avoided the stress from the temperature changes but they did avoid the stress caused by the wave action. Sea scallops do not grow well and exhibit lower survival rates when grown in gear exposed to wave action (Frenette 2004; Lanteigne 2000, Kingzett and Boume 1990).

The OysterGro[®] and the Kenny cabin are rigid gears therefore they probably offer more resistance to the wave action than Lantern nets when used for suspended aquaculture. Consequently, the scallops inside these gears are probably in a more stable environment which may have contributed to the high survival rates. Farmers interested in using these gears should, however, be aware that they are not as easy to handle or to stack as the traditional Lantern nets. The OysterGro[®] and the Kenny cabin would require more storage and probably more manpower. Therefore, their cost-effectiveness based on production versus labor costs should be assessed before a grower can confidently choose these gears above the traditional gear. The Dark Sea trays may be an interesting third choice. The survival rate ($84.2\% \pm 16.1$) of scallops was higher in Dark Sea tray but not significantly than in the traditional Lantern nets and Dark Sea trays were easier to handle and stack than the OysterGro[®] or the Kenny cabin. Presently, Fermes Marines du Québec Inc. is successfully culturing sea scallops off Newport Québec. During the first year, they are using plastic cages called the FMQC-cage which is similar to the Dark Sea tray (pers. comm. Jean-Philippe Hébert). Nevertheless, during the second year and third year they are using Lantern nets because they are easier to handle and stack.

Differences in temperature and food level have been attributed to be the main influence on the growth rate in sea scallops (Côté *et al.* 1993; Couturier *et al.* 1995; MacDonald and Thompson 1985a, 1985b and 1986). Yet, many factors influence the growth rate of cultivated sea scallops: stocking density, size of scallops, gear type, deployment time, depth, season and location (Grecian *et al.* 2000, 2003). In this study the stocking density in each gear type was standardized by following Imai's (1977) stocking guideline. The initial size and deployment time were the same for all the gear types employed and the study was conducted at only one site. Therefore, the main variables, in this study, were the gear type and the depth: in suspension or on the bottom. Sea scallops are benthic filter feeders that mainly feed on phytoplankton (Parsons and Robinson 2006). Monitoring the phytoplankton would have been required to measure the scallop's food availability. Since the aim in this study was to find ways of reducing the low survival rate which was thought to have been caused by the stress of sudden temperature fluctuations (Nowlan *et al.* 2011) only the temperature was monitored.

The highest yearly growth rates of 0.078 ± 0.015 mm/day and 0.079 ± 0.019 mm/day were observed in the Kenny cabins and the traditional Lantern nets respectively. Similar annual growth rate values of 0.072 mm/day and 0.08 mm/day were observed in sea scallops cultured in Passamaquoddy Bay NB Canada using cages and ear hanging respectively. In general, results from this study do confirm Parsons and Robinsons (2006) findings that the growth rate of suspended scallops is faster than those on the bottom. However, in the second year, the growth rate of scallops in the suspended OysterGro[®] was lower than in some of the scallops cultivated on the bottom. The suspended OysterGro[®] were literally covered with *Hiatella* fouling while the other suspended gear were substantially less fouled. Claereboudt *et al.* (1994), who studied fouling development on suspended cultivation gear and its effects on the growth of juvenile sea scallop, reported that fouling has a negative impact on the scallop's growth rate.

Sea scallops occur naturally at temperatures ranging from below 0°C to 18°C (Couturier *et al.* 1995). However, the growth rate of sea scallops is reduced when temperatures are below 8°C and is inhibited at temperatures below 4°C (Young-Lai and Aiken 1986). The rate of development increases with rising temperature until it reaches a plateau at some optimum temperature. The temperature range for sea scallop's optimal growth is between 10°C and 15°C (Pogsey 1953; Young-Lai and Aiken 1986; Stewart and Arnold 1994; Frenette 2004). As temperature increases above the optimum, the growth rate declines. Temperatures of 23.5°C or higher are lethal to sea

scallops and temperatures between 21°C and 23.5°C for a prolonged period of time, are also lethal (Dickie 1958; Stewart and Arnold 1994; Frenette, 2004). The temperature at the study site was above 8°C during the summer and fall and never reached higher than 16°C. Since the average daily temperature never surpassed the warmer temperature at which the sea scallop growth is reduced, it was not included in the growth degree days (GDD) calculations. One of the factors contributing to the higher growth rate of the scallops in the suspended gear is likely the higher GDD (1005.3) that they experienced compared to the GDD (753.5) experienced by the scallops on the bottom.

Sea scallop spat settlement can vary temporally and spatially both on a local and regional level therefore many important factors should be considered if scallop settlement is to be maximized (Parsons and Robinson 2006). The spatial pattern of spat settlement closely reflects the known oceanographic properties of the area (Robinson et al. 1992). According to Cropp and Frankish (1988) spat collection bags must provide over 500 scallop spat/bag with minimal amounts of other species or debris or silt in the bags for a site to be commercially viable for spat collection. The average sea scallop spat count was 451.33 ± 97.45 and it did not vary significantly from the 500 spat/bag. Therefore the sea scallop spat count/bag collected at the Kenny Aquaculture site does meet one of the "economically viable" criteria. However, the spat collectors exhibited high numbers of other species; mainly Iceland scallop (*Chlamys islandica*) and Hiatella (*Hiatella arctica*) which are also filter feeders and compete with the sea scallop spat for food (Fr  chette et al. 2000). However, they do not have byssus like the blue mussels (*Mytilus edulis*) that entrap the scallops and stop them from feeding. Minimizing the capture of unwanted species and maximizing the capture of the sea scallops can be achieved by deploying spat collectors at the optimal time (Cyr et al. 2007). Perhaps with improved spat collection husbandry, unwanted species could be minimized so the Kenny Aquaculture site would fulfill the second criteria required to be a commercially viable scallop spat collection site.

In Nova Scotia, several mussel growers such as Long Reef Shellfish, Indian Point Marine Farms Ltd, Corkum's Island Mussel Farm and Turple Blue Bay Mussel Farm have diversified by the incorporation of sea scallop aquaculture into their operations (pers. comm. .B. Bond, P. Darnell, D. Cook, W. Turple). Traditional Pearl nets and Lantern nets are being used on three of these farms and the fourth one is using Vexar[®] bags on tables. According to the owner/operator of Long Reef Shellfish, growing scallops for the first few years was a challenge and fouling can be minimized by changing the nets in the early fall. In Qu  bec, three companies are farming sea scallops: Pec-Nord, Fermes Marines du Qu  bec and Culti-mer, based on the North Shore, Newport Gasp  sie and   les-de-la-Madeleine respectively. The three companies employ more than 30 people annually on a seasonal or year-round basis and help diversify the economy of these regions. Sea scallop aquaculture is an innovative activity that straddles fisheries and agriculture (Fortier 2013). Base on the growth and survival rates of the cultured scallops and the sea scallops spat collection rates observed in this study, growing sea scallops in Chaleur Bay could be successful, as it is in other parts of Atlantic Canada.

5.0 CONCLUSION

1. The aquaculture gear type with the best performance in terms of scallop growth rate (0.078 ± 0.015 mm/d) and survival rate ($99.2\% \pm 2.0$) was the Kenny cabin.
2. When sea scallops are grown in flexible gear and are exposed to wave action, they exhibit lower survival rates than those grown in rigid gear.
3. Since the rigid gear, OysterGro[®] and Kenny cabin, would require more storage and probably more manpower, their cost-effectiveness based on production versus the labor cost should be assessed before a grower can confidently choose these gears above the flexible Lantern net, the traditional gear.

4. The growth rate of suspended scallops is faster than those on the bottom unless the suspended culture gear is heavily fouled.
5. The Kenny Aquaculture Ltd's farm site could potentially serve as a sea scallop spat collection site based on the average sea scallop spat count ($451.33 \pm 97.45/\text{bag}$). However, the spat collection husbandry needs to be improved to minimize the unwanted species in the bags.
6. Base on the growth and survival rates of the cultured scallops and the sea scallops spat collection rates observed in this study, growing sea scallops in Chaleur Bay could be successful, as it is in other parts of Atlantic Canada.

6.0 ACKNOWLEDGEMENT

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